UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A SINGLE-PHASE PWM-BASED DC-TO-DC CONVERTER FOR ELECTRIC BICYCLE

ALI OMAR AHMAD ALMATHNANI

DEVELOPMENT OF A SINGLE-PHASE PWM-BASED DC-TO-DC CONVERTER FOR ELECTRIC BICYCLE

By

ALI OMAR AHMAD ALMATHNANI

Thesis submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

April 2000

Dedicated

To my Parents, Wife, Daughters, Brothers and Sisters

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

DEVELOPMENT OF A SINGLE-PHASE PWM-BASED DC-TO-DC CONVERTER FOR AN ELECTRIC BICYCLE

BY

ALI OMAR AHMAD ALMATHNANI

April 2000

Chairman: Dr. Ishak Bin Aris

Faculty: Engineering

An electric bicycle is a bicycle that can be operated automatically or manually. The main difference between an electric bicycle and a normal bicycle is that the speed controller of the DC motor attached to the electric bicycle can control the speed of the electric bicycle.

It is suitable for a short distance transportation mode. The advantages of the electric bicycle include better speed performance, no pollution, convenient to use, inexpensive and require less maintenance.

The objective of this project was to develop a single-phase PWM-based DC-to-DC converter for an electric bicycle. The electric bicycle consisted of a lead-acid battery, a DC-to-DC converter, a permanent magnet DC motors and the bicycle itself.

The single-phase converter used pulse width modulation (PWM) switching with an *Insulated Gate Bipolar Transistor (IGBT)* as power device. The speed of the motors was controlled through the duty cycle of the PWM signal.

A protection circuit for the converter was also included in the design. A voltage level monitoring system was developed for the electric bicycle to monitor its lead-acid battery voltage level.

A new bicycle pulley system was designed and constructed to integrate mechanical and electrical parts of the bicycle.

Results of the experimental and simulation showed that there was a good agreement between the hardware and the software. This indicates that the single-phase PWM based DC-to-DC converter was successfully developed.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PEMBANGUNAN PENUKAR ARUS TERUS KE ARUS TERUS BERASASKAN FASA TUNGGAL PWM UNTUK BASIKAL ELEKTRIK

Oleh

ALI OMAR AHMAD ALMATHNANI

April 2000

Pengerusi: **Dr. Ishak bin Aris**

Fakulti: **Kejuruteraan**

Basikal elektrik ialah sebuah basikal yang boleh beroperasi secara automatik atau manual. Perbezaan yang utama yang terdapat pada basikal elektrik ialah kelajuan basikal elektrik dikawal dengan menggunakan sebuah alat pengawal kelajuan motor arus terus yaug berada pada basikal tersebut.

Ianya sesuai digunakan sebagai pengangkutan jarak dekat. Kelebihan basikal elektrik ini ialah ianya mempunyai tahap kelajuan yang baik, tiada pencemaran, senang digunakan, tidak mahal dan kos penyelnggarsn yang murah.

Tujuan utama projek ini adalah untuk membangunkan sebuah penukar arus terus ke arus terus berasaskan fasa tunggal PWM untuk basikal elektrik. Basikal elektrik ini terdiri dari bateri sel basah, penukar arus terus ke arus terus, motor arus terus magnet kekal dan basikal ini sendiri.

Penukar arus terus ke arus terus satu fasa dikawal dengan menggunakan skima pensuisan PWM. *Insulated Gate Bipolar Transistor (IGBT)* digunakan di dalam litar ini. Kelajuan motor yang digunakan boleh dikawal dengan melaraskan kitar masa isyarat PWM.

Ciri-ciri perlindungan dimasukkan juga di dalam litar penukar ini. Sistem pemantau paras voltan dibangunkan bagi basikal ini untuk memantau paras voltan bateri sel basah basikal ini.

Sebuah sistem takal baru telah direka dan dibina untuk menghubungkan bahagian mekanikal dan bahagian elektrial basikal ini. Keputusan ujikaji dan simulasi dari projek ini menunjukkan persamaan yaag baik di antara mereka. Hasil dari ujikaji ini, ianya boleh disimpulkan bahawa penukar arus terus ke arus terus bagi basikal elektrik telah berjaya dibangunkan.

ACKNOWLEDGEMENTS

I would like first to thank our mighty Allah SWT for shedding on me health, and keeping my brain working to the extend of completing this research, which I hope will contribute to the welfare of our nation.

I wish to express my profound gratitude to my supervisor, Dr. Ishak Bin Aris, a lecturer in the Department of Electrical and Electronic Engineering, Universiti Putra Malaysia, for his supervision, guidance, support, unlimited assistance and beneficial advise throughout the period of my study.

Grateful thanks and appreciation are extended to the members of the supervisory committee Dr. Ir. Norman Mariun, and R.K.Z.Sahbudin. My thanks are also extended to the staff at the Graduate School Office for their help and cooperation. My appreciation and gratitude to all the individuals at the Department of Electrical and Electronics Engineering, who had been cooperative.

I would like to extend my thanks to Dr. Abdelmatlub El-Tobuli for his assistance in editing this work. Also my thanks and appreciation are due to my colleagues at the CASC for their help and suggestions during the research work, and to all my friends here in Malaysia and back in Libya.

Finally, I would like to forward my appreciation to my parents, my wife and daughters for their support and confidence in me.

I certify that an Examination Committee met on 14 April 2000 to conduct the final examination of Ali Omar Al-Mathnani, on his Master of Science thesis entitled "Development of A Single-Phase PWM-Based DC-to-DC Converter for Electric Bicycle" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

BAMBANG SUNARYO SUPARJO, Ph.D.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

ISHAK ARIS, Ph.D.,PEng
Faculty of Engineering
Universiti Putra Malaysia
(Member)

NORMAN MARIUN, Ph.D.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

RATNA SAHBUDIN, LECTURER.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

MOHD. GHAZALI MOHAYIDIN, Ph.D.
Professor/Deputy Dean of Graduate School
Universiti Putra Malaysia

Date: 29 APR 2000

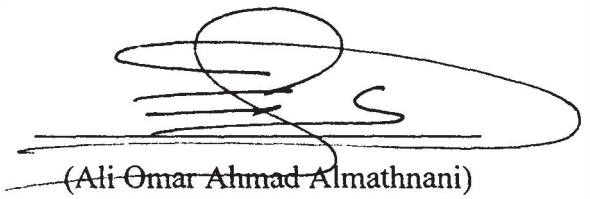
This thesis was submitted to the Senate of Universiti Putra Malaysia and was accepted fulfilment of the requirements for the degree of Master of Science.

KAMIS AWANG, Ph.D.
Associate Professor/Dean of Graduate School
Universiti Putra Malaysia

Date: 8 JUN 2000

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



(Ali Omar Ahmad Almathnani)

Date: 29 – 4 – 2000

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternative Current (A)
BJT	Bipolar Junction Transistor
CEMF	Counter Electric Motive Force
C	Collector
DC	Direct Current (A)
EB	Electric Bicycle
E_s	Supply Voltage (V)
ESR	Effective Series Resistance
E	Emitter
F	Frequency of Chopping (Hz)
F_c	Cut Off Frequency (Hz)
FWD	Free Wheeling Diode
G	Gate
hp	Horse Power (W)
IGBT	Insulated Gate Bipolar Transistor
I_X	Generation Excitation
I	Total Current Supplied to the Armature (A)
J	Junction ,or Energy Density (Joule)
I_a	Armature Current (A)
$I_{a,\ avg}$	Average Load Current of Step-Down (Buck) Converter (A)
$I_{c,\ avg.}$	Average Capacitor Current (A)
K_g	Kilogram
L	Inductance (H)

LED	Light Emitting Diode
MOSFET	Metal-Oxide Silicon Field Effect Transistor
PWMIC	Pulse Width Modulation Integrated Circuit
Pi	Input Power (Watt)
PM	Permanent Magnet
PCB	Printer Circuit Board
PWM	Pulse Width Modulation
Q_G	Total Gate Charge.
R	Resistance of Ward-Leonard Speed Control System(Ohm)
R_a	Resistance of the Armature Circuit (Ohm)
R_G	Gate Resistance (Ohm)
rms	Root Mean Squared
rpm	Revulsion per Minutes
S	Heat Sink
T	Torque Developed by the Motor (N-M)
Tj	Junction Temperature (C^o/W)
T_{JA}	Juncttion to Ambient Temperature (C^o)
$V_{a,avg}$	Average Output Voltage (Volt)
V_c	Control Voltage (Volt)
V_{ce}	Collector-Emitter Voltage (Volt)
V_g	Gate Voltage (Volt)
V_m	Motor Voltage (Volt)
V_o	RMS. Value of Output Voltage (Volt)
V_r	Reference Voltage (Volt)
V_{out}	Output Voltage (Volt)

V_s	Source Voltage (Volt)
V_Q	Transistor Voltage (Volt)
V_L	Load Voltage (Volt)
w_m	Speed of Arınature (rad/sec)
Φ	Flux Pole (Webers)
ΔI	Peak-to- Peak Ripple Current
ΔI_{max}	Maximum Ripple Current
ζ	Emissivity of the Heat sink
θjc	Thermal Resistance (C^o/W)
η	Efficiency

CHAPTER I

INTRODUCTION

Why is an Electric Bicycle Important?

The electric bicycle is expected to become a very important means for short distance transport because of its convenient use, cheapness and minimal maintenance required. Moreover, it is almost pollution free and operates quietly.

The general structure of the electric bicycle is shown in Figure 1. Basically it consists of a lead-acid battery, a DC-to-DC converter, a permanent magnet DC motor and the bicycle itself. The speed of the bicycle is controlled by varying the duty cycle of the PWM signal used to operate the DC-to-DC converter.

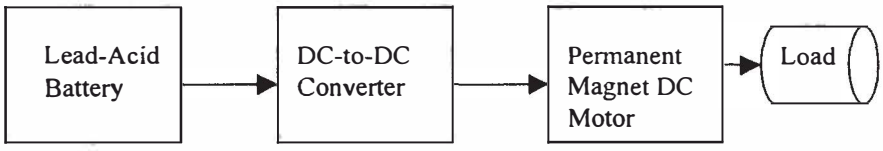


Figure 1: Block Diagram of an Electric Bicycle

Objective of the Project

This project aims to develop an electric bicycle. To achieve this, the following works were carried out.

- Development of a single-phase DC-to-DC converter.
- Development of protection circuits.
- Development of a voltage level monitoring system.
- Development of a bicycle pulley system.

Thesis Layout

This thesis is divided into five chapters. Chapter One gives a short introduction to the work and its objectives. Chapter Two reviews the literature on the electric bicycle, and discusses briefly its importance in modern life. A general study of the DC-to-DC converter, including its control circuit, is also presented.

The work done, including designing the drive circuit of IGBT, control and protection circuits for the DC motor, are presented in Chapter Three. The performances of the DC-to-DC converter and control circuit are discussed in Chapter Four. Finally, Chapter Five presents the conclusions and suggestions for further work.

CHAPTER II

LITERATURE REVIEW

The Electric Bicycle

With air pollution increasing in severity, especially in urban areas, from the growing use of petrol/diesel vehicles, electric bicycles are being looked at as a better mode of transport (Hsu *et al.*, 1989). They produce considerably less pollution than the nearest comparable mode of transport- the motor cycle.

An electric bicycle for transport would have many advantages. Powered by a small electric motor and sipping electric energy from a battery (rechargeable by solar power or the mains), it produces no pollution. Being light, it is convenient to use and can even be peddled to skimp on or dispense with electricity. Under power, a smooth ride is obtained. It can, of course, also be ridden in hybrid mode using both peddling and electric power.

The manual part of the bicycle is simply a pair of pedals driving the rear wheel through a chain and sprockets (Chou, 1994) although modern bicycles would also have gears and a clutch. The electric power is provided by a DC motor drawing electricity from a battery.

Typically, the bicycle would be able to run two to three hours on a full charge and the depleted battery takes six hours to recharge (Hsu *et al.*, 1989).

Lead-Acid Battery

Despite its limitations, the lead-acid battery is still the only practical battery for the electric bicycle although the modern version is but only slightly improved from its predecessors at the turn of the century. Most, if not all, of the other rechargeable batteries available commercially today easily outperform the lead-acid battery technically, and nickel batteries are increasingly looked at for possible use. But for the moment, their limitations outweigh their advantages.

The battery, as shown in Figure 2, comprises the following.

- Cathode attached to the negative terminal,
- Anode attached to the positive terminal, and
- Electrolytic solution such as sodium chloride.

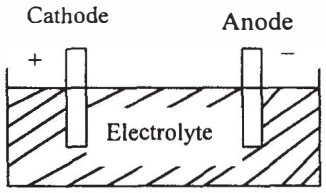


Figure 2: Circuit Diagram of the Lead-Acid Battery

A battery is an electrochemical cell which can be used to deliver current or power to a load. The number of cells are connected in series determines the